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TITLE OF PROJECT: PULSED LASER SHEAROGRAPHY SYSTEM FOR DEFENCE RESEARCH AND EDUCATION
PRINCIPAL INVESTIGATOR: V. ARANCHUK
SECURITY CLASSIFICATION: UNCLASSIFIED

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Pulsed Laser Shearography System for Defense Research and Education

LONG-TERM GOALS

The University of Mississippi purchased a pulsed digital shearography system for research and education involving vibration analysis under the Defense University Research Instrumentation Program (DURIP). This system will be used to conduct research in detection of buried mines, improvised explosive devices (IEDs), and unexploded ordnance for the Office of Naval Research, as well as in research in non-destructive testing and evaluation, measurement of vibration in aeronautical wind tunnel models, and other applications requiring rapid, whole field measurement of vibrations and deformations over relatively large areas.

OBJECTIVES

The objective of this program is to acquire a pulsed digital shearography system for use in research and education.

APPROACH

The University of Mississippi issued a subcontract to MetroLaser, Inc., to procure from MetroLaser, Inc., a custom double pulse shearography system with pixelated, instantaneous phase shifting interferometry. The system would allow recording of phase resolved shearograms of objects subjected to dynamic loading using pulsed lasers. The system would allow measurements of approximately one square meter area objects at two meters distance vibrating in the frequency range from 20 Hz to 50 kHz.

Principal Investigator Dr. Vyacheslav Aranchuk provided expertise in laser-based vibration measurement technologies and acoustic detection. The system has been constructed by MetroLaser, Inc.

WORK COMPLETED

The pulsed laser shearography system has been built and delivered to the University of Mississippi. The shearography system includes the following major parts:

1. Double-Pulse Laser
2. Seed Laser
3. Programmable Delay Generator
4. Transmitter module
5. Shearography head
6. Desktop Computer with 4Sight Software and custom LabView software

A functional layout of the system is shown in Figure 1.

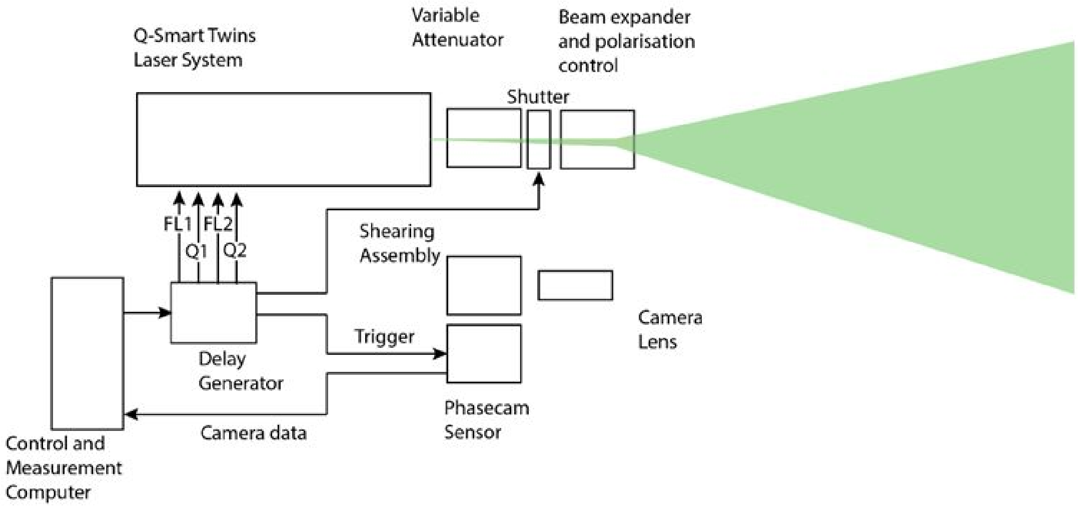

Figure 1. Functional layout of the pulse shearography system.

A photograph of the shearography system setup in the laboratory is shown in Figure 2.

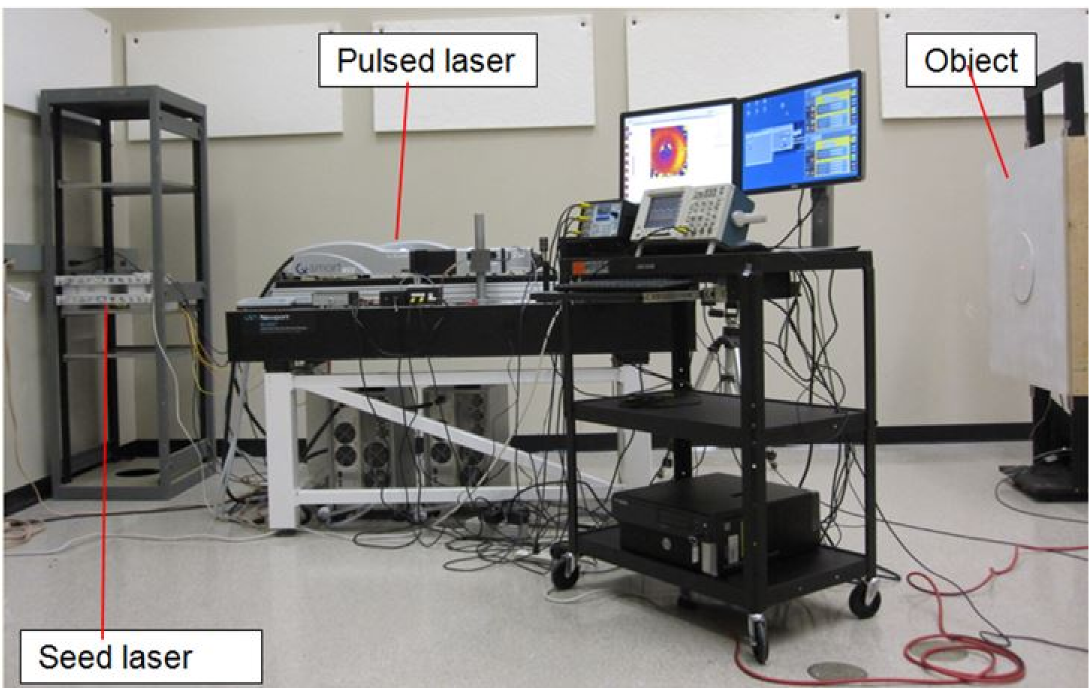

Figure 2. A photograph of the pulsed shearography system setup.

Figure 3 shows a photograph of the optical hardware of the shearography system.

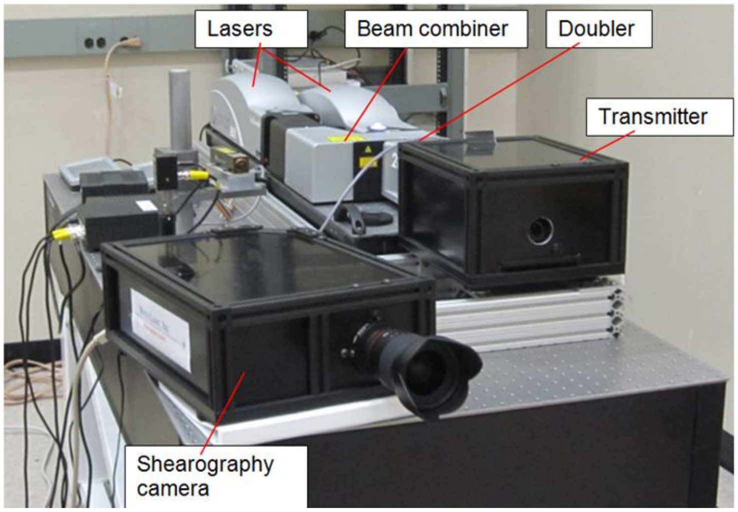

Figure 3. A photograph of the optical hardware of the pulsed shearography system.

The shearography system uses a double-pulse laser system Q-Smart Twins (Quantel, Corp) shown in Figure 3 [1]. The system consists of two coupled Quantel Q-Smart lasers. Each of the lasers produces 9 ns duration pulses, approximately 300 mJ pulse energy at a wavelength of 532 nm and a repetition rate of 10 Hz. Each of the lasers is controlled independently. The laser system incorporates an integrated beam-combining module and a frequency doubler. The two main lasers are seeded by a fiber-coupled seed laser shown in Figure 2. The transmitter module that follows the laser system includes a variable attenuator, a mechanical shutter, a beam expander, and a polarization control module. The attenuator allows for reduced laser beam power operation. The shutter is used to gate out a single pair of pulses. The beam expander and polarization control module expands the laser beam to illuminate the required object area. This module also contains a rotatable half-wave plate which allows adjustment of the laser beam polarization direction. The shearography head includes a camera lens, a shearing interferometer optics and a micropolarizer camera (Phasecam sensor). The micropolarizer camera 4DCam™ from 4D Technology, based on a 1 Megapixel CCD sensor (Illunis RMV-1010) is used in the setup. The camera allows asynchronous double-exposure mode, meaning that the sequence of two frames can be triggered externally. Timing and control are handled by the control and measurement computer and a multi-channel delay generator, which provides trigger signals for the camera and for the laser system flash lamps FL1 and FL2, and Q-switches Q1 and Q2. The same computer runs the 4Sight™ software that provides live video of single and parsed polarization images, intensity, and wrapped and unwrapped phase measurements. A camera lens and the shearing Mach-Zehnder interferometer create two sheared images of the object on the micropolarizer camera. The camera operates in a double-exposure mode. Operation of the camera and the lasers is synchronized with a 10 Hz clock from the delay generator (BNC 577). The operation of the system is based on the instantaneous phase measurements of the optical wavefront using the micropolarizer camera technique [2,3].The system is capable of obtaining phase wrapped and unwrapped shearograms of objects subjected to dynamic deformation during the time between the two laser pulses ranging from 30 μs to 30 ms. This range of separation times of laser pulses allows application of the system for measuring dynamic deformation of objects at different speeds of loading. For example, the system allows measurement of vibration in the frequency range from 17 Hz to 50 kHz, assuming that the separation time between laser pulses is equal to a half period of vibration period. The system allows measuring objects of approximately one square meter of surface area at a distance of two meters.

The pulsed shearography system performance was evaluated by taking shearograms of a vibrating object. The system was used to measure vibration of a circumferentially clamped 200 mm diameter and 5 mm thick plywood plate, shown in Figures 2 and 4. The vibration of the plate was excited with a loudspeaker positioned behind the object, as shown in Figure 4 (b). A laser Doppler vibrometer (LDV) was used to measure vibration at the center of the plate. Shearograms of the vibrating plate were taken for laser 1 and laser 2 pulses synchronized with the peak and trough of the plate vibration, as shown in Figure 5. The plate was excited at the frequency of its fundamental mode, 350 Hz. The separation time between the laser pulses was equal to 1.43 ms, corresponding to a half period of vibration.

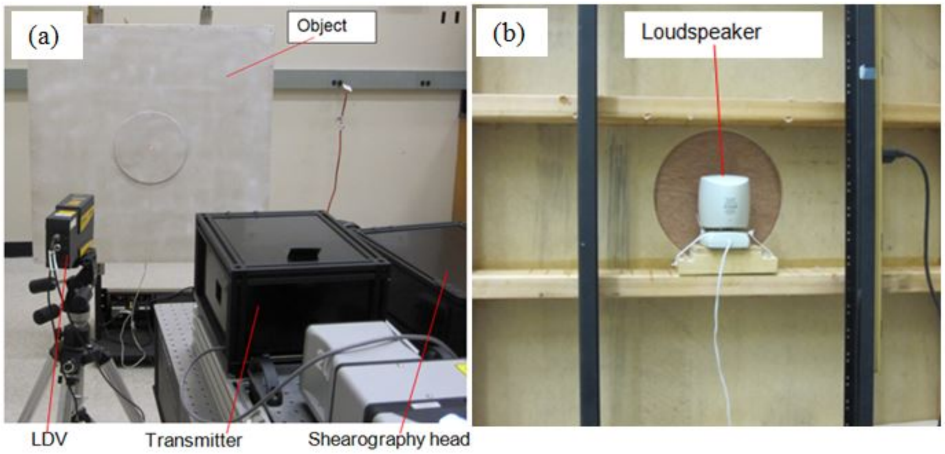

Figure 4. Photographs of the experimental setup for taking shearograms of a vibrating object (a), and a loudspeaker mounted behind the object (b).

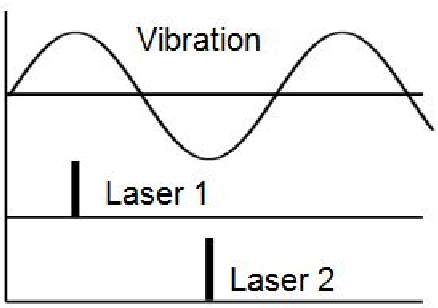

Figure 5. Timing diagram of laser pulses synchronized with peak and trough of object vibration.

Figure 6 shows an example of a double-pulse shearogram of the vibrating 200 mm diameter plywood plate obtained for 100 mm shear in the object plane. The vibration amplitude was 140 nm rms in the center of the plate measured with the LDV. The object was located at 2 m distance from the shearography system. The example presented in Figure 6 shows the wrapped phase map (a), the filtered wrapped phase map (b), and the unwrapped phase map (c) shearogram with X- and Y- profiles. The experimental results demonstrated the ability of the double-pulse shearography system based on a micropolarizer camera to produce shearograms of objects subjected to dynamic loading, for example vibration, using only two laser pulses. The displacement resolution for the vibration measurements was experimentally evaluated to be in the range 15-20 nm rms.

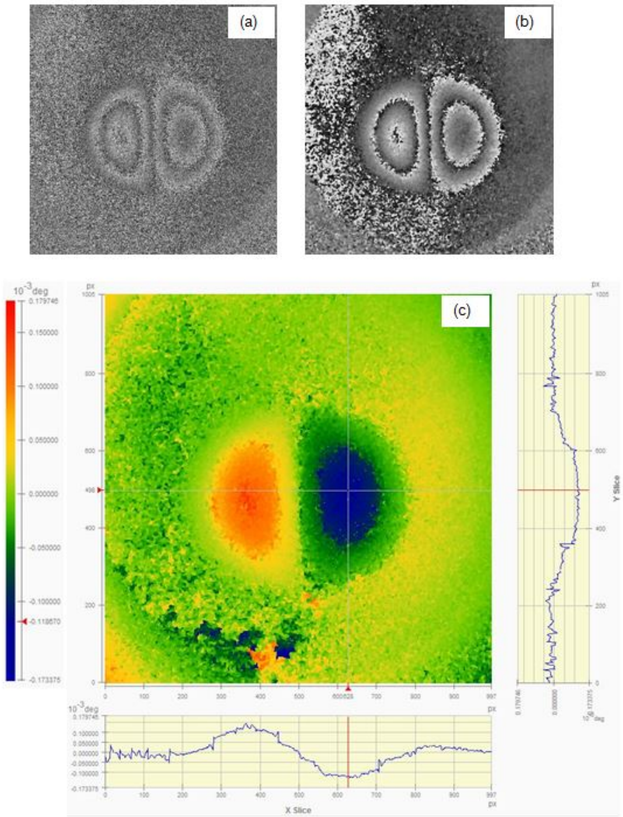

Figure 6. Double-pulse shearogram of a vibrating plate. (a) - wrapped phase, (b) - filtered wrapped phase, (c) - unwrapped phase and profiles.

RESULTS

The pulsed digital shearography system has been built, delivered to the University of Mississippi, and tested. The system is capable of producing phase wrapped and unwrapped shearograms of objects of approximately one square meter surface area from a distance of two meters. The system is capable of measuring the dynamic deformation of the object during the time between the two laser pulses ranging from 30 μs to 30 ms. The system can provide phase unwrapped shearograms of vibrating objects with displacement resolution of 15-20 nm.

RELATED PROJECTS

There are two other projects ongoing at the University of Mississippi that are related to acoustic-seismic detection of buried objects. These include:

- The Office of Naval Research is sponsoring research in the detection of buried objects in littoral regions, with special emphasis on the use of digital shearography (ONR N00014-16-C-3038 "Rapid detection of buried and concealed objects using pulsed digital shearography").

- The Office of Naval Research is sponsoring research in the development of a laser multi-beam differential interferometric sensor based on laser Doppler techniques for acoustic detection (ONR N00014-17-1-2332 "Enhancement of Laser Multi-Beam Differential Interferometric Sensor and Seismic Vibration Response of Targets").

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PUBLICATIONS

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

A pulsed digital shearography system has been purchased by the University of Mississippi under the DURIP program. The system is capable of producing phase wrapped and unwrapped shearograms of approximately one square meter surface area from a distance of two meters. The system can measure dynamic deformation of objects during the time between the two laser pulses ranging from 30 μs to 30 ms.

15. SUBJECT TERMS

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